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Review

Science communication in the field of fundamental biomedical research (editorial)

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ABSTRACT

The aim of this special issue on science communication is to inspire and help scientists who are taking part or want to take part in science communication and engage with the wider public, clinicians, other scientists or policy makers. For this, some articles provide concise and accessible advice to individual scientists, science networks, or learned societies on how to communicate effectively; others share rationales, objectives and aims, experiences, implementation strategies and resources derived from existing long-term science communication initiatives. Although this issue is primarily addressing scientists working in the field of biomedical research, much of it similarly applies to scientists from other disciplines. Furthermore, we hope that this issue will also be used as a helpful resource by academic science communicators and social scientists, as a collection that highlights some of the major communication challenges that the biomedical sciences face, and which provides interesting case studies of initiatives that use a breadth of strategies to address these challenges. In this editorial, we first discuss why we should communicate our science and contemplate some of the different approaches, aspirations and definitions of science communication. We then address the specific challenges that researchers in the biomedical sciences are faced with when engaging with wider audiences. Finally, we explain the rationales and contents of the different articles in this issue and the various science communication initiatives and strategies discussed in each of them, whilst also providing some information on the wide range of further science communication activities in the biomedical sciences that could not all be covered here.

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"The wise see knowledge and action as one" (Bhagvad Gita)

1. Introduction

This special issue has primarily been put together for scientists from the biomedical research field. However, we envisage that it will be useful also to scientists from other fields who are taking part or are planning to take part in science communication, as well as to professional/academic science communicators or social scientists (from now on referred to as 'science communicators'). The motivation for editing this special issue was born out of the observation that there are many excellent science communication initiatives by biomedical scientists (from now on referred to as 'scientists'), yet very few of them are publicised in biomedical journals or in science communication journals. We believe this to be due to the fact that few biomedical journals seem to appreciate the importance of these initiatives for their own scientific field, whilst most journals in the science communication field seem not to consider the work by these initiatives sufficiently academic to suit their readership.

This issue intends to bridge this apparent gap between scientists and science communicators, by providing a forum in a biomedical journal for both groups. For scientists this is an opportunity to publish outstanding science communication work without having to provide in-depth research for every statement they make, or to refer to science communication concepts and use terms and phrases unfamiliar to them. Rather, we asked the authors to describe their initiatives, rationales, good and bad experiences, strategies and resources. This will hopefully inspire other scientists to start communicating their science or improve the strategies they use. For science communicators this special issue is an opportunity to reach out to scientists and use plain language to explain and raise awareness of concepts, strategies and helpful practices developed in the field of academic science communication – hopefully also raising awareness amongst science communicators that the actual strategies they study have to be similarly applied to their own ways of communication by reaching out to non-specialists who can then benefit. Furthermore, we hope that science communicators will feel inspired to capitalise on the resources provided in this issue and use them as potential case studies for their own research.

Writing articles at the interface of biology and science communication is a challenge, and we are most grateful to the authors, all of whom were prepared to engage in this experiment. Therefore, we encourage scientists and science communicators to step back from their usual expectations for publications in their own fields, and to instead use this special issue as an inspiration to how the gap between the different disciplines could be narrowed or closed, thereby paving the way to more effective interdisciplinary collaboration and cross-fertilisation.

We believe that such interdisciplinary collaborations between scientists and science communicators would be of mutual interest and benefit. For scientists, engaging the public with their fundamental research is of enormous importance to address adverse views about science in society and to help improve science literacy (*e.g.* through the advisory and collaborative involvement of scientists in the design of school science curricula [1,2]). Unfortunately, as explained in Section 4, communicating fundamental science is a particularly challenging task, and scientists could enormously benefit from the collaboration with science communication experts to improve their effectiveness. For science communicators, interdisciplinary collaborations with scientists provide an opportunity to look beyond the usual examples commonly referred to in their field (*e.g.* climate change, fracking, genetic crops, *etc.*) and to study the enormous wealth of excellent science communication initiatives developed by those working in the field of fundamental biomedical research – often doing so without any pre-knowledge of science communication strategies.

In this editorial, we will first explain why more scientists should take part in science communication, but also address and explain two barriers that may hamper such activities: the lack of knowledge most scientists have about concepts and strategies of science communication, and the specific challenges that scientists face in engaging with the public. We will then explain the rationale and content of the articles in this issue and how they may help those scientists that are taking part or want to take part in science communication.

2. Why should biomedical scientists engage in science communication?

Science and science education are of important benefit to society, not only through promoting economic gain but also through promoting and sustaining social values [1–3]. Accordingly, the British Science Association (BSA) states as their vision "a future where science is seen as a fundamental part of culture and society at large, instead of set apart from it" [4]. Whilst these arguments might be too abstract to provide an incentive for scientists to engage with the public, others have more immediate relevance; for example, the development of dialogue between scientists and the wider public as well as policymakers, is an important strategy to counteract mutual misconceptions and may have important implications for future directions of science funding [1,2,5–9,131]. It has been suggested that scientists might perhaps no longer have a choice as to *if* they should communicate but should rather focus on *how* to do so effectively ([10] and references therein). Those who are taking part in science communication already, likely do so for a number of reasons; for example, they respond to expectations from their funders, have a passion for their subject and a desire to communicate and inspire, hold a belief that their science is of interest to the public, feel a need to defend science from misconception, recognise the need to build trust, see a benefit for themselves or their institutions, or realise opportunities for involving the public in their own research [6,10–14]. It has also been pointed out that favourable conditions play an important role, with scientists more likely to communicate their science if they have an established position and dedicated funding, if they are supported by their institution, or if they have a strong reason to believe that their engagement will be successful [10] . Therefore, improving external factors is one major challenge that needs to be addressed by decision and policy makers [13], but finding the right motivation is a challenge that concerns us all. We hope that the examples of well-established science communication initiatives in this issue will inspire more scientists to engage with wider audiences and that those who are engaging already feel reassured and get new ideas to further improve their strategies.

3. Understanding concepts and pitfalls of science communication

Science communication rationales, aims and strategies are widely researched by science communicators [6,15,16], but perhaps too little of this filters through to scientists who are actively engaging with the public [17–19]. We feel one important reason for this gap to be that the strategies and concepts of the academic science communication field are not well enough communicated to non-specialist audiences (see Section 5.1). In our view, this hypothesis deserves serious investigation which could, in turn, provide new opportunities and incentives for true interdisciplinary collaborations between science communicators and scientists; such collaborations will be of great benefit, especially when considering that the field of science communication is so complex that it defies a singular definition [20]. Taking one example, Burns and colleagues define science communication as:

> "...the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science (the AEIOU vowel analogy): Awareness, Enjoyment, Interest, Opinion-forming, and Understanding" (p.183 in [21])

This very inclusive definition reflects an enormous diversity in three areas: (A) the variety of modes in which science communication initiatives can be implemented (i.e. face-to-face, *via* media, or through online interactions; e.g. science fairs, arts collaborations, podium discussions, social media, science buskers and soap box science, online mentoring, school outreach, citizen science, radio programmes, *etc.*) [22]; (B) the wide spectrum of target audiences (*e.g.* schools, the wider public, politicians, patient groups, colleagues of the same field, *etc.*) [23]; (C) the range of objectives for science communication (*e.g.* informing, addressing misconception, building trust, crowd sourcing, recruiting, *etc.*) [24]. This multifaceted nature is also illustrated by the many terms used in the field, such as: widening participation, knowledge exchange advocacy, public engagement, public outreach, public understanding, or public awareness [25] – all of which, including also science education [26] , we gather here under the umbrella term of science communication.

A concise, thoughtful and easy-to-read review by D.B. Short [27] provides a brief history of science communication, focussing on events following publication of the impactful Bodmer report in 1985 [28] (see also the historical introduction in [6]). It raises several relevant issues:

a) Science communication was originally seen as a process whereby scientists fill gaps in the knowledge of the public, a 'top-down' educational approach that was described by the 'deficit model' ([29] and references within). This 'one-way' mode of communication was later recognised as being 'ineffective' at achieving the communication goals and replaced by models of 'two-way' dialogue or even mutual learning where the public is listened to and has an impact on science and research governance [30]. However, in reality, both models are perhaps not exclusive and need to be viewed with sufficient differentiation; for example, having a certain level of knowledge can sometimes be a necessary prerequisite for members of the public to be able to engage in meaningful dialogue with scientists [27], and a gain in knowledge can very well have positive impacts on people's attitude depending on their contexts and pre-knowledge [29].
b) We need to frame our science communication carefully, to avoid promoting false expectations that can back-fire [27]: for example, over-selling 'benefits to society' including economic gain and quality-of-life improvements derived from fundamental science, may have facilitated mistrust or false expectations by the public (including decision- and policymakers), and encouraged a rising demand for more applied/translational science with expected short-term returns. Moreover, living in "post-truth" times may also affect the ways in which science is communicated and/or viewed, and proactive science communication – with intelligent framing – might be even more important under these circumstances in order to maintain (or re-gain) wider agreement with, trust in, and support for fundamental research as an important pillar of science [31–34].
c) Science communication is driven by different groups including politicians, scientists, science institutions, funding or patient organisations, and learned societies, which might all have very different viewpoints when setting their objectives for effective communication and engagement. Science communication might easily be misused for political or commercial purposes, which might no longer represent the kind of science communication that was originally intended by the scientists who chose to engage with the public. For this reason, informed and transparent objective setting with a clear awareness of who the beneficiaries are is as important when planning ones engagement [22,35], as it is to maintain independence from commercial interests (see the example of EuroStemCell [36]).

Whilst scientists might be interested in some of the ideas that D.B. Short discusses in his review, it is important to point out that not all of these ideas are universally agreed upon. For example, some science communciators might argue that there is no threshold of knowledge needed to engage in dialogue, or that using science communication as a recruitment drive to encourage students to pursue scientific careers is a good thing. These different views and approaches serve to demonstrate how tricky it can be for scientists who are new to communicating their research, and how difficult it can be to navigate the literature, nomenclature, and attitudes surrounding science communication.

4. Fundamental biomedical sciences lack 'natural' target audiences

Apart from finding the motivation to engage (Section 2), and the prevailing lack of knowledge about concepts of science communication (Section 3), there are other important barriers that can stand in the way of science communication by scientists [13,37]. These include: (1) a potential lack of external reward (*e.g.* involvement may not be valued and might even harm professional promotion; case studies or communication strategies can only rarely be published in biomedical journals of sufficient reputation), (2) the difficulty to obtain (continued) funding, and (3) frustration and fatigue caused by the enormous challenge of sustaining an initiative until it reaches momentum and measurable impact (if ever!).

Achieving momentum and impact is particularly relevant for scientists who want to communicate topics of fundamental research that have no direct path to application [130]. Those working in translational biomedical research on topics that concern disease treatment and improvement of life quality (*e.g.* cancer, neurodegeneration, stem cells) will have a 'naturally' motivated audience amongst those who are affected and are seeking for help and advice (Section 5.2.1; [36]), and this might similarly be the case for topics like food security or sustainability. Those of us who communicate with clinicians to achieve collaboration, may be able to build on a shared scientific goal that is mutually attractive (Section 5.2.2.; [38]); similarly, African researchers were reported to be highly motivated to collaborate on the DrosAfrica project because they saw important opportunities to improve their scientific standing (Section 5.2.2.; [39]). However, without such 'natural' incentives, the only obvious motivations for target audiences to engage are curiosity or an interest in learning (as is expressed and explained in Fig. 1), which are less likely to serve as a solid and self- sustaining driver for a science communication initiative. As a further challenge, fundamental science and its most recent achievements are often not easy to convey and may require extra layers of explanation, to introduce non-experts to fundamental science concepts that underpin new discoveries. This needs extra time and thought, and it seems therefore no surprise that engagement with audiences too often stays at a very basic level. Paige Jarreau stated about this problem on Twitter (@FromTheLabBench, 1 Aug 2017): "Wow, out of 1000+ sci museum Instagram posts we've analyzed (w/@nicoledahmen) only 8 posts TOTAL discuss a recent sci discovery/finding".

We therefore believe that it requires extra stamina to drive effective science communication initiatives in the fundamental

Fig. 1. Cover illustration by Matt Girling.
"The idea behind the cover art image is to represent the communication of biology to the general public. To show the public as accurately as possible I have worked from sketches that I made of the people of Manchester, including a teacher, a clinician and a politician as they are key figures for which it is particularly important to communicate information to. The representation of "biology" is expressive and abstract; as an artist and a non-expert in biology I looked for a way to depict scientific knowledge as a mysterious and intricate energy to catch the eye of somebody who might ordinarily have no interest in biology. A zebrafish, fruit fly and mouse have also been included as they have special relevance in many areas of biological research." (Matt Girling, mattgirlingartist.tumblr.com). To add to this, we, the authors, also feel that these images relate to the spirit of illustrations drawn for Alice's Adventures in Wonderland, thus referring to a time in the second half of the 19th century that was particularly open to discovery, curiosity, science and technology.

sciences, and that doing so requires long-term, objective-driven approaches. Such approaches make it possible to develop a gradually growing pool of high-quality resources, to gain interdisciplinary expertise and, if the initiative can be sustained for long enough, to provide a higher likelihood of gaining momentum and achieving measurable impact (which may then also lead to external reward and other benefits, such as personal promotion, alternative professional perspectives, recognition by peers, *etc.*; see [13]). For this reason, examples provided in Section 5.2 of this issue represent objective-driven, long-term initiatives. We suggest that sustainability can be further improved if initiatives are woven into networks of science communication. Such networks can be facilitated through learned societies or not-for-profit science journals (Section 5.3.) and through interdisciplinary collaborations that may involve schools, social science, the area of law, the arts, and/or the media. In particular, working with schools provides important opportunities for fundamental scientists to engage with the public, as many work in areas directly relevant to the school science curriculum; *via* scientist-teacher collaborations, the scientists' subject knowledge can filter through to schools and lesson contents, and such developments can be of mutual benefit to scientists, teachers and pupils and have potential long-term impact on society (see Section 5.2.3.).

5. Overview of this issue

Articles in this issue can be roughly subdivided into three categories: (1) formal advice for those who are participating or want to participate in science communication; (2) the description of established objective-driven long-term initiatives who share their rationales, aims, strategies, experiences and resources; and (3) analogous information concerning science communication in organisations, societies or scientist networks. Here, we will briefly explain the rationales, stragies and resources of the different articles presented (further examples of science communication initiatives are provided in Box 1 and Box 2).

Box 1: Selection of further long-term, objective-driven science communication initiatives in Cell and Developmental Biology
A more comprehensive list can be found on the website of the British Society of Developmental Biology ('Outreach' tab) [93].

- BioEYES: a scientist-teacher collaboration project initiated by Steven Farber bringing zebrafish practicals into K12 school classes, which has had enormous impact [95,96] .
- "Ciencia Al Tiro" (Science Immediately): science outreach for children of deprived backgrounds in Chile, which has one of the largest gaps in Latin America in performance between the private and public schools [97,98].
- iBiology: an initiative launched by Ron Vale producing online videos by science leaders that make their ideas, stories, and experiences available to anyone, as well as resources for students and educators including online courses [99].
- Instituto Gulbenkian de Ciência (IGC) collaboration with www.everythingisnew.pt: a fundraising program for biomedical research combining music festivals with science communication to generate opportunities for informal science education and public dialogue [100,101].
- Knowing Neurons: initiated by a young group of neuroscientists, their resources explain neuroscience to the general public used in classrooms around the world [102] .
- Microscopy4Kids: a gateway to learning about digital microscopy with resources for educators and kids, including lesson plans and information about microscopes [103].
- Microscopes for Schools (m4s): a hands-on science outreach activity for primary school children run by volunteer scientists from the MRC Laboratory of Molecular Biology (Cambridge, UK) with information about microscopes, cells and feasible experiments, as well as a collection of links [104].
- Teaching & Research in Natural Sciences for Development in Africa (TReND in Africa): a higher education charity run by a small group of young researchers dedicated to improving university level science education and research excellence in sub-Saharan Africa; organises neuroscience courses for young African scientists and aims to establish permanent African research facilities [63,64] .
- The Embryo Project Encyclopaedia: an open access, digital publication by researchers who study the historical and social contexts of reproductive medicine, developmental biology and embryology – to communicate, to research science with historical and computational methods, and to develop university classes and programs [105].
- The Naked Scientist: a radio talk show broadcasted on radio stations internationally, also publishing podcasts (for example in collaboration with the eLife journal) [106] .
- Understanding animal research: a multi-facetted science communication initiative aiming to improve the acceptance of animal use in research by providing resources for journalists, scientists, schools and policy makers [94].
- ZOONIVERSE: a platform to set up citizen science projects calling the public to help with data analysis; although there are currently no biomedical science projects listed [107] , citizen science is a great way to reach out to the public and should be considered [108].

Box 2: Educational and science communication resources by scientific organisations and societies relevant for Cell and Developmental Biology
A more comprehensive list can be found on the website of the British Society of Developmental Biology ("Outreach" tab) [93].

- American Society of Cell Biology (ASCB): educational resources for K12, undergraduate and graduate students and links to Resources in Cell Biology [109].
- American Physiological Society (aps): education resources for schools, undergraduates, postgraduates, continued learning, the public and miorities; support also through publication and numerous awards [110].
- Biochemical Society: an Activities Library and tips to plan your own hands-on activity [111].
- Biotechnology and Biological Sciences Research Council (BBSRC): providing resources and informing about events and strategies [112].
- British Society of Cell Biology (BSCB): a number of education resources [113].
- British Society of Developmental Biology (BSDB): "Advocacy" tab (providing elevator pitches and arguments for advocacy) and "Outreach" tab (a large collection of science communication resources providing general support and/or topic-relevant contents) [93].
- British Science Association (BSA): driving science communication activities and research for a wide range of public audiences [4].
- Centre of the Cell: science education centre based at the Whitechapel Campus of Queen Mary University (London) within an environment of working biomedical research laboratories [114].
- Clarkeson University's "Project-based learning partnership": scientist-teacher collaborations involving student placements [115,116].
- CourseSource: an open-access journal of peer-reviewed teaching resources for college biological science courses, supported by 8 American biological societies [117].
- Faculty for Undergraduate Neuroscience (FUN): international organisation focussed on neuroscience education and research at the undergraduate level; members are businesses and organisations, arts colleges, university departments, individual faculty and students [118].
- Genetics Society (GS): a number of education resources [119].
- Genetics Society of America (GSA): resources for the teaching of genetics and the "Genes to Genomes" blog [120].
- Howard Hughes Medical Institute (hhmi): Educational resources for educators, scientists and the public, the "BioInteractive" newsletter and the Inclusive Excellence Award [121].
- International Society for Stem Cell Research (ISSCR): explaining stem cells *via* FAQs, a glossary and a brochure [122].
- Journal "CBE – Life Science Education": this is the former "Cell Biology Education" journal and is now jointly published by the ASCB and GSA [123].
- Nuffield Foundation: aims to influence education policy and practice and ensure that all young people develop the understanding and skills required to play an informed role in society; training awards and a collection of biology-relevant experiments [124].
- Royal Institution: independent UK charity founded in 1799 dedicated to connecting people with the world of science; provides courses, communication resources, school engagement, STEM grants and the famous Christmas lecture [132]
- Royal Society of Biology: teaching resources for schools and higher education, education research and publication of two journals: The Biologist, J Biological Education [125] .
- Society of Developmental Biology (SDB): a number of education resources [126].

5.1. General science communication advice

As already mentioned in Section 2, science communication as an academic discipline has generated many ideas, concepts and strategies for how to communicate science to specific audiences, and literature is available explaining and advising on key strategies [40–47]. However, scientists hardly find the time to keep up with the literature of their own field, let alone academic science communication literature – even more since the field-specific concepts and terms frequently used and referred to in those publications,

- The Royal Society: aims "to increase the UK's capacity to undertake high quality educational research in order to ensure that education policy and practice are better informed by evidence" [127].
- University of Utah's "Genetic Science Learning Center": simple explanations of genetics, cell biology and human health [128].
- Wellcome Trust: project funding, strategy research, support and resources for science communication and education, including exciting image collections and the school online journal "BigPicture" [129].

are often unfamiliar to non-experts and can therefore be difficult to access for scientists. The article by Sam Illingworth [22] aims to overcome such access barriers by providing a concise and accessible overview of basic tricks and tips for effective science communication and raising awareness of opportunities as well as common mistakes or omissions. Notably, this article has been developed by ScienceSplained (a group of expert scientists providing animated videos for academic websites) on their own initiative into an entertaining YouTube video [48].

A key challenge for science communication initiatives is the evaluation of quality and impact [49–53]. Demonstration of impact (*i.e.* an evidence of change in knowledge, skills or behaviour) is often requested as a quality indicator by funding organisations or during institutional assessments, but evaluation can also be used as an extremely helpful measure to improve quality of individual science communication activities [54,55]. As a major problem associated with evaluations, King et al. (p.1 in [55]) point out that: "providing [impact] is extremely difficult given the narrow constraints of available budgets, staff and methodological expertise within which [informal learning institutions] operate" suggesting that "the emphasis on impact is obfuscating the valuable role of evaluation". Furthermore, we have to be aware of the risk that "engagement becomes more about evaluation and measurement than about altruism, mutual learning, and respect" (p.2 in [12]). Notwithstanding potential problems associated with evaluation, it is pivotal for the sustainability of any long-term science communication initiative to include quality and/or impact evaluation. To facilitate this task, the article by Suzanne Spicer provides a brief and easy-to-understand overview of suitable strategies and methodologies [56].

5.2. *Examples of successful objective-driven long-term initiatives*

5.2.1. *Multifaceted initiatives*

The two articles about EuroStemCell [36] and the Manchester Fly Facility [35] have a number of interesting commonalities: (1) both initiatives aim to raise awareness about a specific science topic (stem cells *versus* fruit fly research) and to address discrepancies between the views of the wider public and field experts; (2) both initiatives started from a single activity (developing a film and website *versus* generating a training package for students), which gradually expanded into multi-facetted initiatives including multiple strategies to target a broad range of audiences; (3) both initiatives aim to develop science communication networks within their specific research communities; for example they use a central website [57,58] and make their developed resources freely available in order to engage with the general public on a wider scale and to animate scientists from their fields to contribute to the communication effort; (4) both initiatives capitalise on interdisciplinary collaborations and combine complementary expertises to widen the range and quality of their activities. However, a major difference between the two initiatives lies in their scopes and target audiences: stem cell science involves an ever increasing group of researchers and clinicians worldwide, as compared to 10–15 K scientists working with *Drosophila* [59]; and there is a 'naturally motivated' target audience (see Section 4) for stem cell research (with 1.3 million unique visitors of the EuroStemCell webpage per annum), whereas *Drosophila* research, although of high translational potential, concerns fundamental bioscience in its core, attracting far less attention (~25 K visitors of the Manchester Fly Facility websites over 3 years). Given these very different circumstances, it is interesting to see how analogous strategies were developed independently by the two different initiatives.

5.2.2. *Scientist-to-scientist communication*

Chao et al. [38] describe how collaborative projects between clinicians and scientists can be achieved; they explain the underlying rationale, implementation strategies, available online tools, and potential mutual gains for the collaborating partners, illustrating this through several concrete examples. Clinicians and scientists have a common fundamental interest (*i.e.* understanding the biology behind disease-linked genes), and both parties can benefit enormosuly by combining their scientific approaches (*i.e.* gene-linkage and study of symptoms in patients *versus* functional dissection of biological/disease mechanisms in animal models or cell culture). However, the challenges lie in the very different scientific education and culture of clinicians and biologists (*i.e.* systemic physiology at the level of organs and the body *versus* mechanistic thinking at the level of molecules, cells and organs). Establishing ways of communication that foster a mutual acceptance and realisation of each other's strengths is essential to achieve successful collaboration, which can then pave the way to a greater and mutually beneficial outcome.

The "DrosAfrica" project described by Martín-Bermudo, Gebel and Palacios [39], aims to "build an African biomedical research community using *Drosophila*" [60–62]. It has common roots with, and still shares important commonalities with "TReND in Africa", a successful charity organisation that focuses on improving the standing of neuroscience in Africa [63–65]. Both initiatives collaborate with scientists in Africa to improve science training and education, the science curriculum, research quality and output, as well as the available infrastructure (see also [66,67]). The overarching aim is to reduce the human capital flight ("brain drain") of experts and to positively impact on economic development. As an efficient but also cost-effective model organism, *Drosophila* can be a driver of such developments, as is illustrated by the role fruit flies played in establishing genetic research in Spain [68]. For researchers in Africa, the cost-saving aspect of fly research can free funds for important infrastructure investments, whilst the uses of *Drosophila* for research on topics such as pesticide resistance [69], mosquito olfaction [70] or *Plasmodium* growth [71,72] provide opportunities in areas that are very relevant to the African continent. In their article, Martín-Bermudo, Gebel and Palacios describe how DrosAfrica is being implemented, providing an important resource for those who would like to establish similar collaborations (*e.g.* [73]).

5.2.3. *Science-teacher collaborations*

Science communication and education are two sides of the same coin [26,74], and schools offer important opportunities to open young people's minds to science. Two articles in this issue explore long-term collaboration initiatives with schools in England. The project described by Kover and Hogge [75] aims to improve teaching of inheritance and evolution in primary schools, and the droso4schools project described by Patel et al. [76] attempts to improve biology teaching through establishing the fruit fly *Drosophila* as a powerful teaching tool in classrooms. Both projects capitalise on long-term collaboration as a very effective strategy, and place university students as teaching assistants in schools: to establish dialogue with teachers, learn about school realities, identify content requirements, and develop school-apt teaching strategies. To achieve momentum and impact, both projects recognise the importance of having a dedicated website to reach out nationally and even internationally [77,78], and they provide purpose-tailored, free-to-download sample lessons to actively involve other teachers that are not collaborating on the project. Both articles talk about the difficult task of actively marketing such projects and in finding teachers who are willing to adopt or adapt the respective teaching resources. The two articles not only address those who want to collaborate with schools in the longterm, but also provide many important insights that are useful for any form of science communication in schools.

5.3. *Science communication through societies or networks of scientists*

Learned societies represent the interests of scientists who share the same scientific interests. They are therefore in an ideal position to coordinate, support, and enhance science communication relevant to specific scientific fields. Various societies in the biomedical sciences have recognised this role and are performing science communication to different degrees (Box 2). To raise awareness of possible strategies, the article by Jeanne Braha [79] describes the various science communication activities available to scientific societies, using primarily examples implemented by the American Association for the Advancement of Science (AAAS) [80], a society with a long-standing and vision-driven tradition in science communication [81]. Activities mentioned in the article by Braha include the support of society members through offering advice, providing resources and training, connecting scientists to audiences, making information available to the public, and awarding prizes for outstanding science communication work. Further examples of science communication activities driven by scientific organisations and learned relevant for biomedical research are provided in Box 2.

Social media present interesting new opportunities for science communication [41,82–84] (but also averse challenges [85]). Here, Vicente et al. [86] explain the rationale and practicalities of The Node [87], a "community [blog] site for and by developmental biologists" and researchers from related fields. The Node is maintained by The Company of Biologists, a "not-for-profit publishing organisation dedicated to supporting and inspiring the biological community" [88]. It provides a field-specific, highly-subscribed-to communication platform which can be used by individuals or societies to write field-relevant, non-commercial blogs (*e.g.* reports about scientific publications, conferences or outreach events, announcements, job adverts, *etc.*), but it also provides services such as collated lists of relevant conferences or science communication resources. In this way, The Node can be viewed as a modern form of newsletter [89]. However, although scientist are usually prominent blog users [90], Vicente et al. report that blog posts on the Node have on "*average less than 1 comment per post (not including jobs)*", suggesting that biologists have a low tendency to engage with the medium (see also [35]). The Node tries to compensate for this by using also Twitter and Facebook as complementary social media platforms but even this outreach is limited when considering that only about 10% of first/last authors publishing in the journal Development use Twitter (Aidan Maartens, pers. comm.). These various communication strategies explained by Vicente et al., provide a useful resource for societies and other scientist networks aiming to enhance interaction and collaboration within their communities and beyond (for further examples see [91] and [92]).

6. Conclusions and future perspectives

As discussed in the introduction, science communication initiatives vary widely in terms of mode of delivery, target audience, and overall aims and objectives. This special issue provides advice and inspirational examples that demonstrate how simple initial steps or ideas can be developed, through dedication and the pursuit of a clear vision, into long-term projects with a greater reach. It aims to raise the wider appreciation of science communication activities and, thereby, improve the condition of those who are actively involved (*e.g.* help with professional promotion, recognition by peers, alternative professional careers, etc.). Some of the articles in this special issue also demonstrate how scientists can go beyond face-to-face communication, through sharing resources and strategies online and, eventually, forming networks of science communication where resources and workload can be distributed. In the biomedical sciences, such an approach is urgently required to improve the standing of fundamental research in society, and this is where we as individuals, but also journals, societies or other organisations, can play a key part in helping to communicate and develop our field. We hope that the articles collected in this special issue provide an impetus for this development, and that in reading them you feel encouraged to communicate your science effectively and inspired to work with others to develop interdisciplinary collaborations that address both scientific and societal needs effectively.

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References

[1] H.L. Allen, Lessons from the United Kingdom's Royal Society, Thought Action 26 (2010) 115–120.
[2] The Royal Society, The Scientific Century: Securing Our Future Prosperity (RS Policy Document 02/10), The Royal Society, London, 2010.
[3] V. Rull, The most important application of science, EMBO Rep. 15 (9) (2014) 919–922.
[4] British Science Association, Making Science a Fundamental Part of Culture and Society, 2016, https://www.britishscienceassociation.org/ (Accessed 23 May 2017).
[5] G. Rowe, D. Rawsthorne, T. Scarpello, J.R. Dainty, Public engagement in research funding: a study of public capabilities and engagement methodology, Public Underst. Sci. 19 (2) (2010) 225–239.
[6] A. Grand, G. Davies, R. Holliman, A. Adams, Mapping public engagement with research in a UK University, PLoS One 10 (4) (2015) e0121874.
[7] J. Besley, The National Science Foundation's science and technology survey and support for science funding, 2006–2014, Public Underst. Sci. 3 (2016) (096366251664980).
[8] L. Bornmann, Measuring the societal impact of research: research is less and less assessed on scientific impact alone—we should aim to quantify the increasingly important contributions of science to society, EMBO Rep. 13 (8) (2012) 673–676.
[9] A.B. Van Riper, What the public thinks it knows about science, popular culture and its role in shaping the public's perception of science and scientists, EMBO Rep. 4 (12) (2003) 1104–1107.
[10] J. Besley, A. Dudo, Scientists' views about public engagement and science communication in the context of climate change, Oxf. Res. Encycl. Clim. Sci. 380 (2017) 1–28, http://dx.doi.org/10.1093/acrefore/9780190228620.013.
[11] S.E. Palmer, R.A. Schibeci, What conceptions of science communication are espoused by science research funding bodies? Public Underst. Sci. 23 (5) (2012) 511–527.
[12] L. Fogg-Rogers, A. Grand, M. Sardo, Beyond dissemination- science communication as impact, J. Sci. Commun. 14 (03) (2015) C01.

[13] A. Prokop, S. Illingworth, Aiming for long-term, objective-driven science communication in the UK, F1000Research 5 (2016) 1540.
[14] M.R. Roberts, Realizing societal benefit from academic research: analysis of the National Science Foundation's broader impacts criterion, Soc. Epistemol. 23 (3–4) (2009) 199–219.
[15] K. Hall Jamieson, D. Kahan, D.A. Scheufele, The Oxford Handbook of the Science of Science Communication, Oxford Library of Psychology, Oxford University Press, Oxford, New York, 2017 (p. 512).
[16] M. Bucchi, B. Trench, Routledge Handbook of Public Communication of Science and Technology, Routledge, 2014, pp. 274.
[17] R. Grossman, Science Communication: Could You Explain It to Your Granny? (article in The Guardian), 2014, https://www.theguardian.com/science/blog/2014/oct/10/science-communicators-quantum-physics-granny (Accessed 05 June 2017).
[18] S.E. Brownell, J.V. Price, L. Steinman, Science communication to the general public: why we need to teach undergraduate and graduate students this skill as part of their formal scientific training, J. Undergrad. Neurosci. Educ. 12 (1) (2013) E6–E10.
[19] J.C. Besley, A. Dudo, M. Storksdieck, Scientists' views about communication training, J. Res. Sci. Teach. 52 (2) (2015) 199–220.
[20] T. Bubela, M.C. Nisbet, R. Borchelt, F. Brunger, C. Critchley, E. Einsiedel, G. Geller, A. Gupta, J. Hampel, R. Hyde-Lay, E.W. Jandciu, S.A. Jones, P. Kolopack, S. Lane, T. Lougheed, B. Nerlich, U. Ogbogu, K. O'Riordan, C. Ouellette, M. Spear, S. Strauss, T. Thavaratnam, L. Willemse, T. Caulfield, Science communication reconsidered, Nat. Biotechnol. 27 (6) (2009) 514–518.
[21] T.W. Burns, D.J. O'Connor, S.M. Stocklmayer, Science communication: a contemporary definition, Public Underst. Sci. 12 (2) (2003) 183–202.
[22] S. Illingworth, Delivering effective science communication: advice from a professional science communicator, Semin. Cell Dev. Biol. 70 (2017) 10–16 http://www.sciencedirect.com/science/article/pii/S1084952117301933.
[23] S. Patel, A. Prokop, How to develop objective-driven comprehensive science outreach initiatives aiming at multiple audiences, bioRxiv (2015), http://dx.doi.org/10.1101/023838.
[24] R.A. Logan, Science mass communication: its conceptual history, Sci. Commun. 23 (2) (2001) 135–163.
[25] S. Illingworth, J. Redfern, S. Millington, S. Gray, What's in a name? Exploring the nomenclature of science communication in the UK, F1000Research 4 (409) (2015) https://f1000research.com/articles/4-409/v2.
[26] A. Baram-Tsabari, J. Osborne, Bridging science education and science communication research, J. Res. Sci. Teach. 52 (2) (2015) 135–144.
[27] D.B. Short, The public understanding of science: 30 years of the Bodmer report, Sch. Sci. Rev. 95 (350) (2013) 39–44.
[28] W.F. Bodmer, The Public Understanding of Science. Report of a Royal Society Ad Hoc Group Endorsed by the Council of the Royal Society, 1985, http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/1985/10700.pdf (Accessed 23 May 2017).
[29] P. Sturgis, N. Allum, Science in society: re-evaluating the deficit model of public attitudes, Public Underst. Sci. 13 (1) (2004) 55–74.
[30] A. Irwin, Risk, science and public communication: third- order thinking about scientific culture, in: M. Bucchi, B. Trench (Eds.), Handbook of Public Communication of Science and Technology, Routledge, Oxford (UK), 2008, pp. 199–212.
[31] R. Armon, Beyond Facts and Lies: Science in a Post-truth Era, 2017, https://sagepus.blogspot.co.uk/2017/07/beyond-facts-and-lies-science-in-post.html (Accessed 22 July 2017).
[32] Nature editorial, Researchers should reach beyond the science bubble, Nature 542 (2017) 391.
[33] A. Makri, Give the public the tools to trust scientists, Nature 541 (2017) 261.
[34] P. Williamson, Take the time and effort to correct misinformation, Nature 540 (2017) 171.
[35] S. Patel, A. Prokop, The Manchester Fly Facility: implementing an objective-driven long-term science communication initiative, Semin. Cell Dev. Biol. 70 (2017) 38–48 http://www.sciencedirect.com/science/article/pii/S1084952117303312.
[36] J. Barfoot, K. Doherty, C.C. Blackburn, EuroStemCell: a European infrastructure for communication and engagement with stem cell research, Semin. Cell Dev. Biol. 70 (2017) 26–37 http://www.sciencedirect.com/science/article/pii/S1084952117304457.
[37] B. Hamlyn, M. Shanahan, H. Lewis, E. O'Donoghue, T. Hanson, K. Burchell, Factors Affecting Public Engagement by Researchers. A Study on Behalf of a Consortium of Uk Public Research Funders (JN129116), TNS BMRB, 2015, pp. 1–69.
[38] H.-T. Chao, L. Liu, H.J. Bellen, Building dialogues between clinical and biomedical research through cross-species collaborations, Semin. Cell Dev. Biol. 70 (2017) 49–57 http://www.sciencedirect.com/science/article/pii/S1084952117302604.
[39] M.D. Martín-Bermudo, L. Gebel, I.M. Palacios, DrosAfrica: Building an African biomedical research community using Drosophila, Semin. Cell Dev. Biol. 70 (2017) 58–64 http://www.sciencedirect.com/science/article/pii/S1084952117304895.
[40] S.J. Cooke, A.J. Gallagher, N.M. Sopinka, V.M. Nguyen, R.A. Skubel, N. Hammerschlag, S. Boon, N. Young, A.J. Danylchuk, Considerations for effective science communication, FACETS 2 (2017) 233.
[41] M.J. Kuchner, Marketing for Scientists: How to Shine in Tough Times, 1st ed., Island Press, Washington, DC, 2012.
[42] C. Dean, Am I Making Myself Clear? A Scientist's Guide to Talking to the Public, 1st ed., Harvard University Press, Cambridge, MA, 2009.
[43] N. Baron, Escape from the Ivory Tower: A Guide to Making Your Science Matter, 1st ed., Island Press, Washington, DC, 2010.
[44] R. Olson, Don't Be Such a Scientist: Talking Substance in an Age of Style, 1st ed., Island Press, Washington, DC, 2009.
[45] R. Olson, Houston, We Have a Narrative: Why Science Needs Story, 1st ed., University of Chicago Press, Chicago, 2015.
[46] J.E. Harmon, A.G. Gross, The Craft of Scientific Communication, 1st ed., University of Chicago Press, Chicago, 2010.
[47] S. Illingworth, G. Allen, Effective Science Communication, A Practical Guide to Surviving as a Scientist, IOP Publishing, 2016.
[48] ScienceSplained, YouTube Channel, 2017, https://www.youtube.com/watch?v=D8jEsfFTQzU (Accessed 14 July 2017).
[49] N. Federico, P. Giuseppe, Assessing the impact of science communication, in: M. Bucchi, B. Trench (Eds.), Routledge Handbook of Public Communication of Science and Technology, Routledge, 2014.
[50] E.A. Jensen, Evaluating impact and quality of experience in the 21 st century: using technology to narrow the gap between science communication research and practice, J. Sci. Commun. 14 (03) (2015) C05.
[51] E. Jensen, The problems with science communication evaluation, J. Sci. Commun. 13 (01) (2014) C04.
[52] E. Jensen, Highlighting the value of impact evaluation: enhancing informal science learning and public engagement theory and practice, J. Sci. Commun. 14 (03) (2015) Y05.
[53] Research Councils UK (RCUK), Evaluation: Practical guidelines – a guide for evaluating public engagement activities. http://www.rcuk.ac.uk/documents/publications/evaluationguide-pdf/ (Accessed 14 June 2017).
[54] E. Weitkamp, Between ambition and evidence, J. Sci. Commun. 14 (02) (2015) https://jcom.sissa.it/archive/14/02/JCOM_1402_2015_E.
[55] H. King, K. Steiner, M.A.R. Hobson, H. Clipson, Highlighting the value of evidence-based evaluation: pushing back on demands for 'impact', J. Sci. Commun. 14 (02) (2015) A02.
[56] S. Spicer, The nuts and bolts of evaluating science communication activities, Semin. Cell Dev. Biol. 70 (2017) 17–25 http://www.sciencedirect.com/science/article/pii/S1084952117304640.
[57] EuroStemCell, EuroStemCell. 2008, http://www.eurostemcell.org/ (Accessed 13 June 2017).
[58] Manchester Fly Facility, For the public. http://www.flyfacility.ls.manchester.ac.uk/forthepublic/ (Accessed 30 November 2016).
[59] D. Bilder, K.D. Irvine, Taking stock of the *Drosophila* research ecosystem, Genetics 206 (3) (2017) 1227–1236.
[60] M. Vicente-Crespo, S. Muñoz-Descalzo, T. Weil, M.D. Martín-Bermudo, I. Palacios, Workshop-based training for capacity building: using *Drosophila* to bring research skills to Africa, FASEB J. 30 (1) (2016) (663.2).
[61] DrosAfrica, Building an African biomedical research community using *Drosophila*. http://drosafrica.org (Accessed 14 June 2017).
[62] I.M. Palacios, DrosAfrica: Background and Workshops, 2017, http://thenode.biologists.com/drosafrica/education/ (Accessed 14 June 2017).
[63] TReND in Africa, Teaching & Research in Natural Sciences for Development in Africa. http://trendinafrica.org/ (Accessed 14 June 2017).
[64] S. Yusuf, T. Baden, L. Prieto-Godino, Bridging the gap: establishing the necessary infrastructure and knowledge for teaching and research in neuroscience in Africa, Metab. Brain Dis. 29 (2) (2014) 217–220.
[65] T.K. Karikari, A.E. Cobham, I.S. Ndams, Building sustainable neuroscience capacity in Africa: the role of non-profit organisations, Metab. Brain Dis. 31 (1) (2016) 3–9.
[66] Adéquation Germany, Developing Opportunities for Life, 2005, http://adequationgermany.embl.de (Accessed 14/06/2017).
[67] Seeding Labs, https://seedinglabs.org (Accessed 14 June 2017).
[68] A. Martinez-Arias, A perspective on the development of genetics in Spain during the XX century, Int. J. Dev. Biol. 53 (8–10) (2009) 1179–1191.
[69] P.J. Daborn, C. Lumb, T.W.R. Harrop, A. Blasetti, S. Pasricha, S. Morin, S.N. Mitchell, M.J. Donnelly, P. Müller, P. Batterham, Using *Drosophila melanogaster* to validate metabolism-based insecticide resistance from insect pests, Insect Biochem. Mol. Biol. 42 (12) (2012) 918–924.
[70] I. Paddibhatla, R.K. Mishra, *Drosophila* as a model for mosquito: olfactory signals and host seeking behaviour, Curr. Sci. 110 (1) (2016) 44–46.
[71] J. Yan, X. Yang, M. Mortin, A. Shahabuddin, Malaria sporozoite antigen-directed genome-wide response in transgenic *Drosophila*, Genesis 47 (3) (2009) 196–203.
[72] S.M. Brandt, G. Jaramillo-Gutierrez, S. Kumar, C. Barillas-Mury, D.S. Schneider, Use of a *Drosophila* model to identify genes regulating *Plasmodium* growth in the mosquito, Genetics 180 (3) (2008) 1671–1678.
[73] Fly Indonesia, Building an Indonesian *Drosophila* community. https://flyindonesia.wordpress.com/ (Accessed 14 June 2017).
[74] G. Clark, J. Russell, P. Enyeart, B. Gracia, A. Wessel, I. Jarmoskaite, D. Polioudakis, Y. Stuart, T. Gonzalez, A. MacKrell, S. Rodenbusch, G.M. Stovall, J.T. Beckham, M. Montgomery, T. Tasneem, J. Jones, S. Simmons, S. Roux, Science educational outreach programs that benefit students and scientists, PLoS Biol. 14 (2) (2016) e1002368.
[75] P. Kover, E. Hogge, Engaging with primary schools: supporting the delivery of the new curriculum in evolution and inheritance, Semin. Cell Dev. Biol (2017) http://www.sciencedirect.com/science/article/pii/S1084952117303804.

[76] S. Patel, S. DeMaine, J. Heafield, L. Bianchi, A. Prokop, The droso4schools project: long-term scientist-teacher collaborations to promote science communication and education in schools, Semin. Cell Dev. Biol. 70 (2017) 73–84 http://www.sciencedirect.com/science/article/pii/S1084952117304111.
[77] Teaching Evolution for Primary Children, Information and resources for primary teachers. https://evolutionforprimarykids.co.uk/ (Accessed 14 June 2017).
[78] droso4schools, Online Resources for School Lessons Using the Fuit Fly *Drosophila*, 2015, https://droso4schools.wordpress.com/ (Accessed 30 November 2016).
[79] J. Braha, Science communication at scientific societies, Semin. Cell Dev. Biol. 70 (2017) 85–89 http://www.sciencedirect.com/science/article/pii/S1084952117302537.
[80] American Association for the Advancement of Science, Programs. http://www.aaas.org/programs/education-programs (Accessed 14 June 2017).
[81] R. Holt, Why science? Why AAAS? Science 347 (6224) (2015) 807.
[82] E. Gibney, Toolbox: how to tame the flood of literature, Nature 513 (2014) 129–130.
[83] S. Illingworth, G. Allen, Establishing an Online Presence, Effective Science Communication, IOP Publishing, 2016, 2017, pp. 7-1-7-17.
[84] C.A. Tachibana, Scientist's Guide To Social Media, 2014, http://www.sciencemag.org/careers/features/2014/02/scientists-guide-social-media (Accessed 14 June 2017).
[85] S.N. Mohammed, The (Dis)information Age: The Persistence of Ignorance, Peter Lang, New York, Bern, Berlin, Bruxelles, Frankfurt am Main, Oxford Wien, 2012.
[86] C. Vicente, A. Maartens, K. Brown, The Node and beyond – using social media in cell and developmental biology, Semin. Cell Dev. Biol. 70 (2017) 90–97 http://www.sciencedirect.com/science/article/pii/S1084952117302513.
[87] The Node, The community site for and by developmental biologists. http://thenode.biologists.com/ (Accessed 14 June 2017).
[88] The Company of Biologists, Supporting biologists inspiring biology. http://www.biologists.com/ (Accessed 14 June 2017).
[89] C.M. Kelty, This is not an article: model organism newsletters and the question of 'open science', BioSocieties 7 (2) (2012) 140–168.
[90] P. Jarreau, B. Porter, Science in the social media age, J. Mass Commun. Q. 8 (2017) (107769901668555).
[91] American Society of Cell biology, ascb post. http://www.ascb.org/ascb-post/ (Accessed 14 June 2017).
[92] Genetics Society of America (GSA), Genes to Genomes. http://genestogenomes.org/ (Accessed 14 June 2017).
[93] British Society of Developmental Biology (BSDB) http://bsdb.org (Accessed 17/ June 2017).
[94] Understanding Animal Research, http://www.understandinganimalresearch.org.uk (Accessed 14 June 2017).
[95] J.R. Shuda, V.G. Butler, R. Vary, S.A. Farber, Project BioEYES: accessible student-driven science for K–12 students and teachers, PLoS Biol. 14 (11) (2016) e2000520.
[96] BioEYES, A partnership to advance K-12 science education. http://www.bioeyes.org (Accessed 17 June 2017).
[97] Ciencia al Tiro, http://www.cienciaaltiro.cl/ (Accessed 17 June 2017).
[98] K. Whitlock, Outreach Program: Ciencia Al Tiro (Science Immediately), 2014, http://thenode.biologists.com/outreach-program-ciencia-al-tiro-science-immediately/outreach/ (Accessed 17 June 2017).
[99] S.S. Goodwin, iBiology: communicating the process of science, Mol. Biol. Cell 25 (15) (2014) 2217–2219.
[100] M.J. Leão, S. Castro, Science and rock, how music festivals can boost the progress of science, EMJO Rep. 13 (11) (2012) 954–958.
[101] M.J. Leão, Science Powered by Music, 2013, http://thenode.biologists.com/science-powered-by-music-2/outreach (Accessed 17 June 2017).
[102] Knowing Neurons, http://knowingneurons.com/ (Accessed 14 June 2017).
[103] Microscopy4Kids, Resources For Kid-Friendly Microscopy. http://microscopy4kids.org (Accessed 17 June 2017).
[104] m4s, Microscopes for schools. http://www2.mrc- lmb.cam.ac.uk/microscopes4schools/ (Accessed 30 November 2016).
[105] The Embryo Project Encyclopedia, Recording and contextualizing the science of embryos, development, and reproduction. https://embryo.asu.edu (Accessed 14 June 2017).
[106] The Naked Scientist, https://www.thenakedscientists.com (Accessed 14 June 2017).
[107] ZOONIVERSE, Projects/Biology. https://www.zooniverse.org/projects/?discipline=biology&page=1&status=live (Accessed 17 June 2017).
[108] J. Cox, E.Y. Oh, B. Simmons, C. Lintott, K. Masters, A. Greenhill, G. Graham, K. Holmes, Defining and measuring success in online citizen science: a case study of Zooniverse projects, Comput. Sci. Eng. 17 (4) (2015) 28–41.
[109] American Society of Cell Biology (ASCB), Educational resources.
[110] American Physiological Society (aps), Education. http://www.the-aps.org/mm/Education (Accessed 18 June 2017).
[111] Biomedical Society, Public engagement resources. http://www.biochemistry.org/Education/PublicEngagement.aspx (Accessed 14 June 2017).
[112] Biotechnology and Biological Sciences Research Council (BBSRC), Public engagement. http://www.bbsrc.ac.uk/engagement/ (Accessed 14 June 2017).
[113] British Society of Cell Biology (BSCB), http://bscb.org/ (Accessed 14 June 2017).
[114] Centre of the Cell, 2015, https://www.centreofthecell.org (Accessed 14 June 2017).
[115] Clarkson University, Project-based learning partership, 2016, http://www.clarkson.edu/highschool/k12/# (Accessed 05 June 2017).
[116] S.E. Powers, B. Brydges, P. Turner, G. Gotham, J.J. Carroll, D.G. Bohl, Successful institutionalization of a K-12-university STEM partnership program (session # AC −1652), in: 115th Annual ASEE Conference & Exposition, Pittsburgh, PA, 2008, p. 2008.
[117] CourseSource, Evidence-based teaching resources for undergraduate biology education/Courses. http://www.coursesource.org/courses (Accessed 14 June 2017).
[118] Faculty for Undergraduate Neuroscience (FUN), https://www.funfaculty.org/drupal (Accessed 14 June 2017).
[119] Genetics Society, Education. http://www.genetics.org.uk/Education.aspx (Accessed 14 July 2017).
[120] Genetics Society of America (GSA), Education. http://www.genetics-gsa.org/education/ (Accessed 14 June 2017).
[121] Howard Hughes Medical Institute (hhmi), Education. https://www.hhmi.org/education (Accessed 14 J UNE 2017).
[122] International Society for Stem Cell Research (ISSCR), Learn about stem cells. http://www.isscr.org (Accessed 14 June 2017).
[123] LSE, CBE - Life Sciences Education. http://www.lifescied.org (Accessed 14 June 2017).
[124] Nuffield Foundation, Practical Biology. http://www.nuffieldfoundation.org/practical-biology (Accessed 14 June 2017).
[125] The Royal Society of Biology, Education. https://www.rsb.org.uk/education/berg/education-research (Accessed 14 June 2017).
[126] Society for Developmental Biolgy (SDB), Education Resources. http://www.sdbonline.org/education_resources (Accessed 14 July 2017).
[127] The Royal Society, Educational Research, https://royalsociety.org/topics-policy/education-skills/education-research/ (Accessed 14 June 2017).
[128] Genetic Science Learning Center, Learn.Genetics, http://learn.genetics.utah.edu/ (Accessed 14 June 2017).
[129] Wellcome Trust, Public engagement. https://wellcome.ac.uk/what-we- do/topics/public-engagement (Accessed 14 June 2017).
[130] R. Borchelt, Communication, Literacy, Policy: Thoughts on SciComm in a Democracy https://www.sigmaxi.org/news/keyed-in/post/keyed-in/2015/09/03/communication-literacy-policy-thoughts-on-scicomm-in-a-democracy, 2015 (Accessed 13 August 2017).
[131] B.A. Cohen, How should novelty be valued in science? Elife 6 (2017) e28699.
[132] The Royal Institution (Ri), Science lives here. http://www.rigb.org/, (Accessed 01 Sept 2017).